RBF Morph software

RBF mesh morphing ACT extension for ANSYS Mechanical

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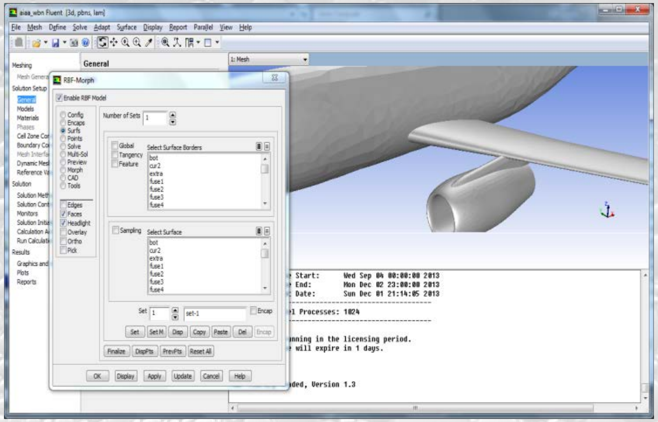
Outline

- Company Introduction
- RBF Morph Software Line
- Ongoing Researches
- Industrial Applications
- Fluent Adjoint Coupling

Company Introduction

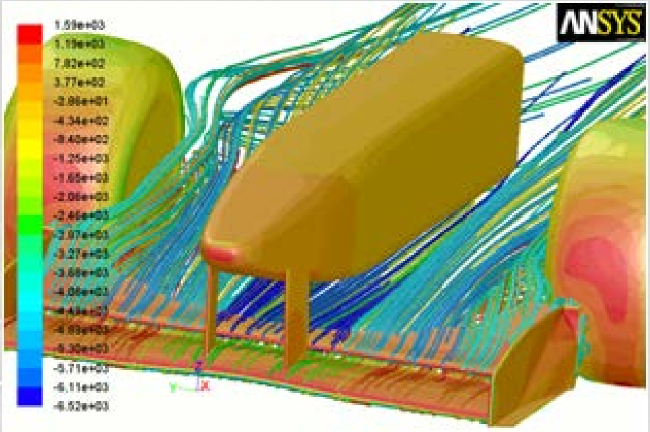
RBF Morph is a pioneer and world-leading provider of numerical morphing techniques and solutions conceived to efficiently handle shape optimization studies concerning most challenging industrial applications.
We are an independent software-house and vendor. Our main product is **RBF Morph**™, that is a unique morpher that combines a very accurate control of the geometrical parameters with an extremely fast mesh smoothing properly designed to be integrated in advanced computational optimization procedures.

The **RBF Morph** tool is currently available in the market mainly as add-on of the CFD commercial code ANSYS® Fluent®.



Company Introduction

The **RBF Morph** tool had its inception in 2008 as on-demand solution for a Formula 1 top team. The need was a novel technology able to change the shape of large CFD numerical models as fast as possible. The final result had been so good that the technology was packaged in a commercial software product and launched onto the market.



At present, Dr. Marco Evangelos Biancolini is the unique owner of the **RBF Morph** technology and, as Director, avails himself of the collaboration of several experts for the deliver of products and services.

Company Introduction

- Morphing-based numerical tools and services
- RBF Morph Milestones
  - ✓ 2008: tool implementation for Formula 1 top team consultancy activity
  - ✓ 2009: founded in Italy
  - ✓ 2009: Software Partner of ANSYS
  - ✓ 2009: at EASC **RBF Morph** won the *Most Advanced Approach Award Most Innovative Approach using Simulation Methods*
  - ✓ 2011: strategic partnership with Tor Vergata University (Rome)
  - ✓ 2012: OEM partner of ANSYS
  - ✓ 2013: beneficiary of an FP7 AAT Project RBF4AERO
  - ✓ 2013: at ASWC **RBF Morph** awarded for the *Best use of HPC*
  - ✓ 2013: Partner of Enginsoft
  - ✓ 2014: beneficiary of FP7 Project RIBES
  - ✓ 2014: beneficiary of FP7 Fortissimo

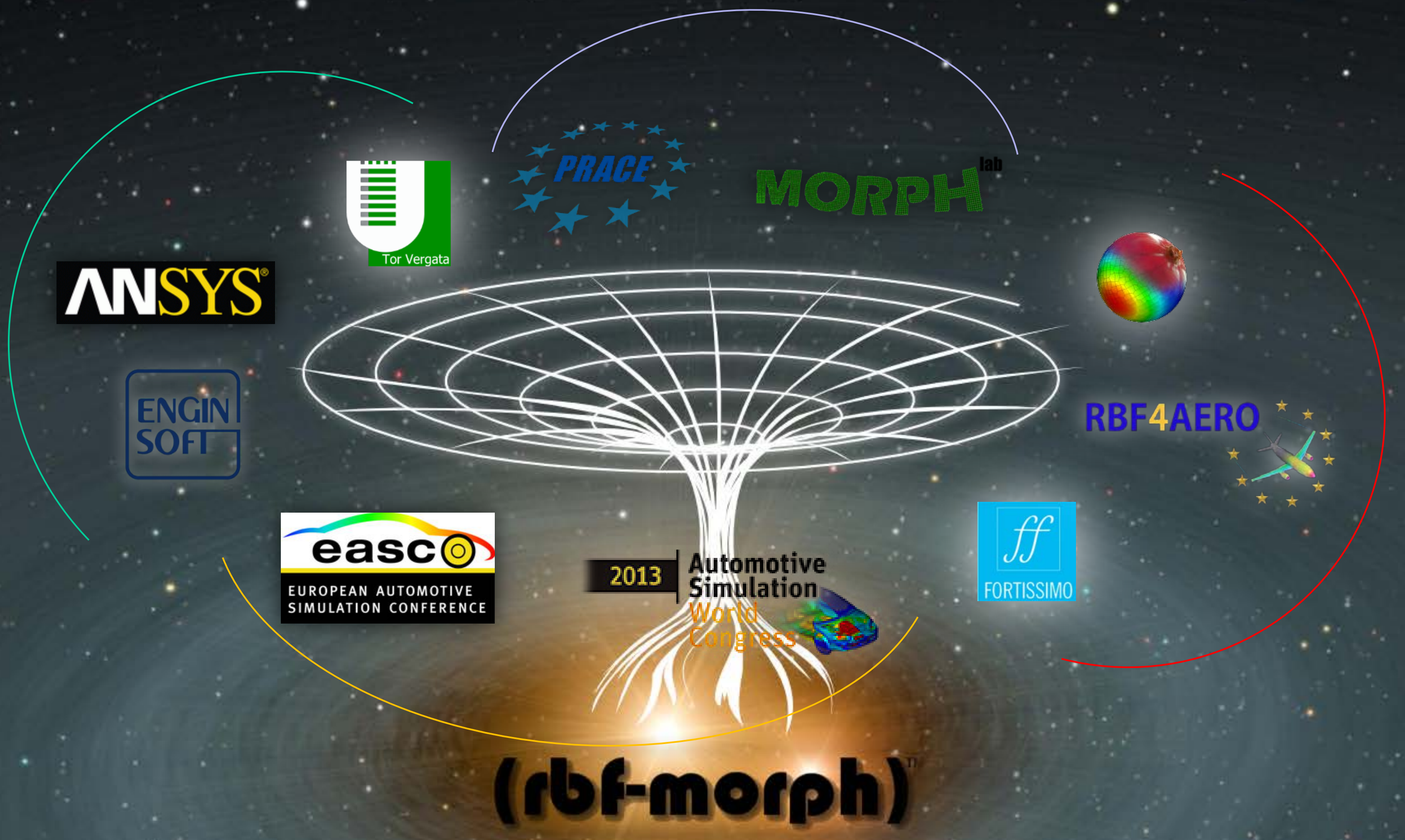
ANSYS

ENGIN SOFT

easco
EUROPEAN AUTOMOTIVE SIMULATION CONFERENCE

2013 Automotive Simulation World Congress

Knowledge Galaxy



RBF Morph software line

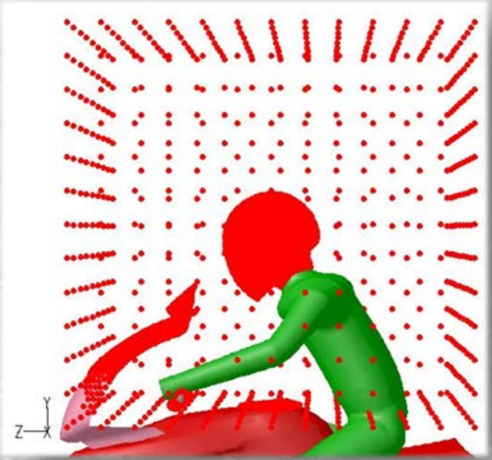
Mesh Morphing with RBF

- A system of **Radial Basis Functions** is used to **fit** a **solution** for the mesh movement/**Morphing**, from a list of **source points** and their **displacements**.

- The RBF problem definition does not depend on the mesh

- Radial Basis Function interpolation is used to derive the displacement in **any location** in the space, each component of the displacement is interpolated:

$$\begin{cases} v_x = s_x(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^x \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ v_y = s_y(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^y \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ v_z = s_z(\mathbf{x}) = \sum_{i=1}^{N} \gamma_i^z \phi\left(\left\|\mathbf{x} - \mathbf{x}_{k_i}\right\|\right) + \beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z \end{cases}$$



- RBF are recognized as on of the **best mathematical tool** for mesh morphing. The main issue is about performances required for the solution of **large dataset**.

RBF Morph software line

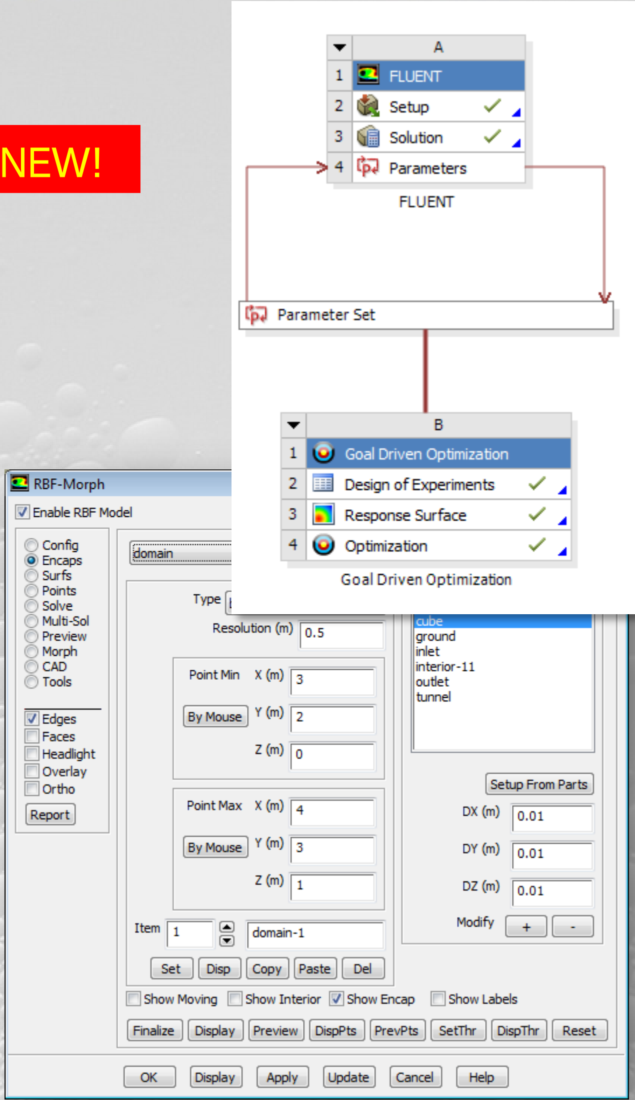
- HPC RBF **general purposes** library (state of the art algorithms, parallel, GPU). This is the numerical kernel of our software. **Millions** of RBF centers can be fitted in a short time.
- Awarded mesh morphing software available as an add-on for **ANSYS Fluent** CFD solver
- **Stand alone** morphing software + smoothing commands for different mesh formats
- ANSYS Mechanical **ACT module** (first beta version already working since June 2014)

Fluent add-on

- **Add on** fully integrated within **Fluent** (GUI, TUI & solving stage), **Workbench** and **Adjoint Solver**

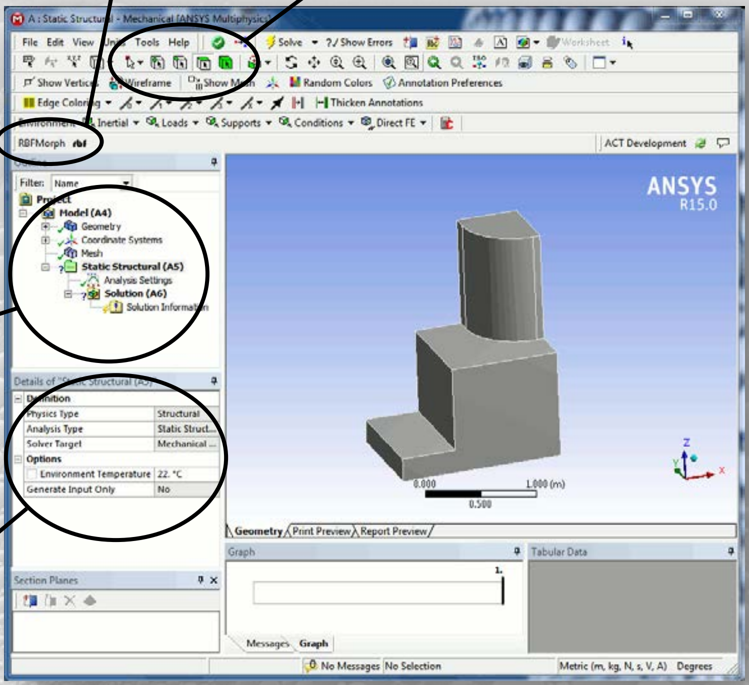
NEW!

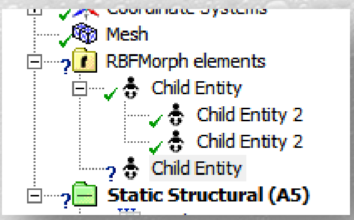
- **Mesh-independent** RBF fit used for surface mesh morphing and volume mesh smoothing
- **Parallel** calculation allows to morph **large size** models (many millions of cells) in a short time
- Management of **every kind of mesh** element type (tetrahedral, hexahedral, polyhedral, etc.)
- Support of the **CAD re-design** of the morphed surfaces
- **Multi fit** makes the Fluent case truly parametric (only 1 mesh is stored)
- **Precision**: exact nodal movement and exact feature preservation (**RBF** are better than **FFD**)

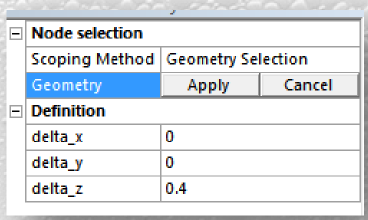


ACT module for Mechanical

- Deeply integrated in ANSYS Mechanical: same look & feel, same interaction logic
- Nested in the usual Mechanical tree as an added object, shares its scoping tools for **geometrical** and **mesh elements** selections
- Written in **python** and **xml**, uses external RBF Morph core libraries
- Child **hierarchical logic** for complex morphings (two steps, three steps, …, n steps setups)

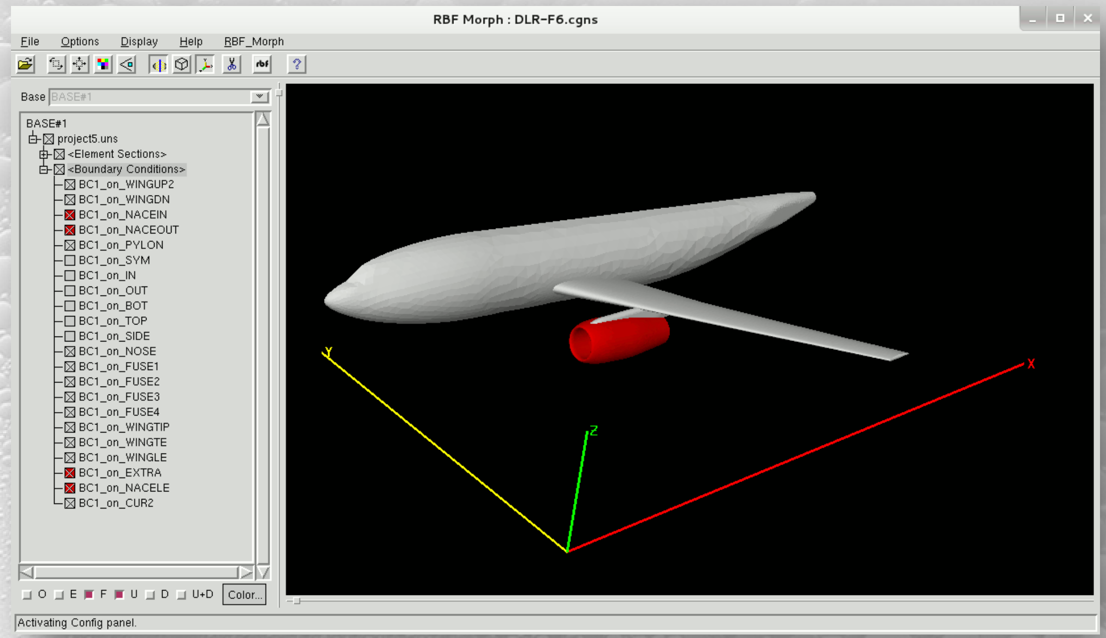






RBF Morph Stand Alone

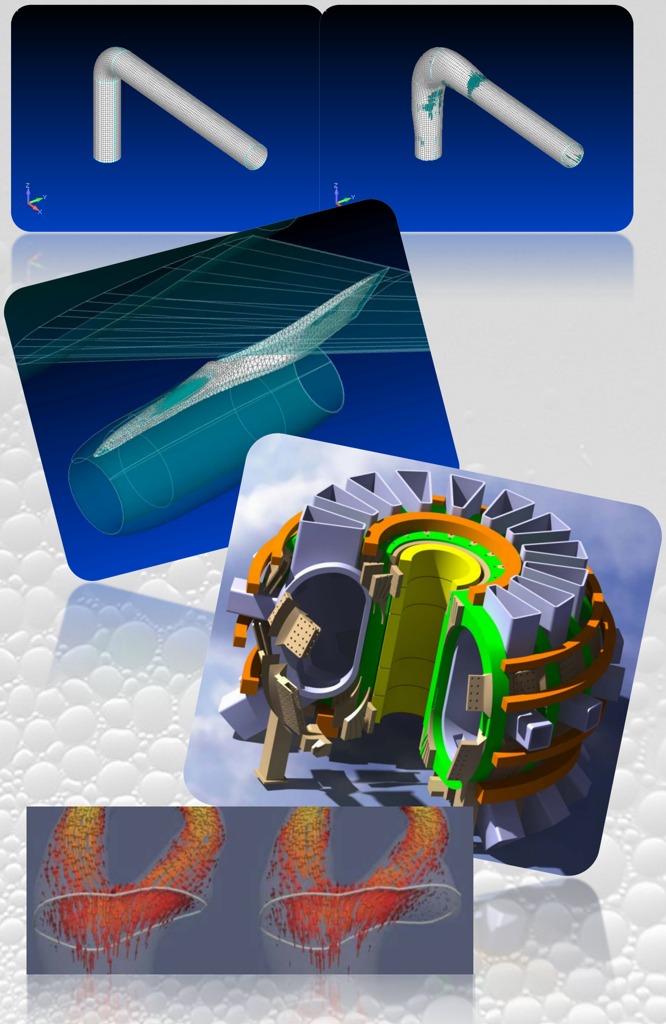
- RBF solutions are fully compatible and **exchangeable** between add-on and standalone versions
- Support for STL and CGNS file formats. Selected morphed surfaces can be exported in STL format and **back to CAD** is possible via STEP files
- **Add-on-like** interface
- **Solver independent** process currently supports many mesh formats
- Functions **scriptable** via tcl
- Global supported bi-harmonic functions and C^0, C^2, C^4 compact supported functions available



Ongoing RBF Morph Researches

Ongoing RBF research

- RBF Morph and Adjoint coupling: Adjoint sculpting, Adjoint preview, Augmented DOE
- **STL** targeting, **CAD** controlled surfaces
- **Mesh to CAD** features
- Mapping of **magnetic** and **pressure** loads
- Interpolation of **hemodynamic** flow fields acquired *in vivo*
- Strain and **stress calculation** (experimental data, coarse FEM, isostatic lines)

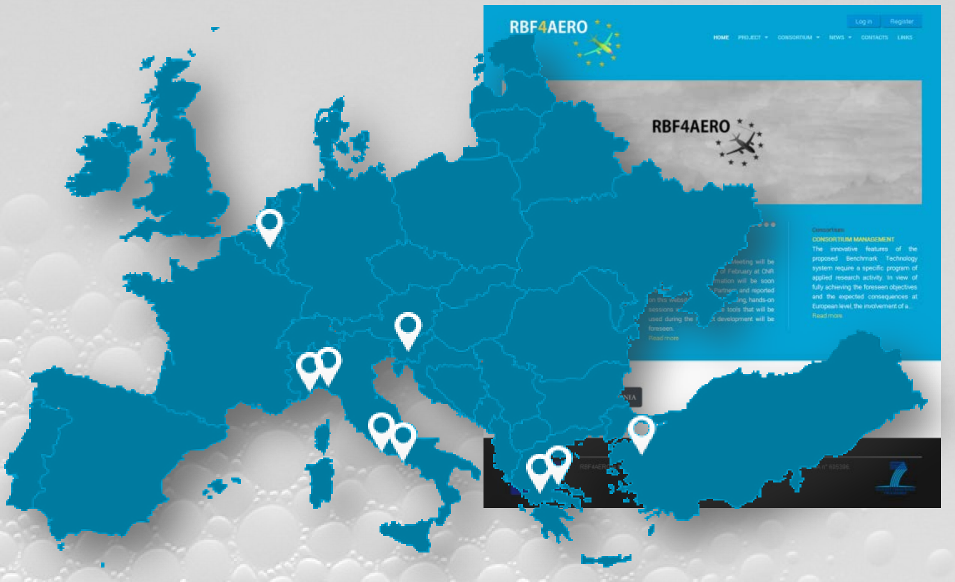


RBF4AERO EU Project

- “Innovative Benchmark Technology for Aircraft Engineering Design and Efficient Design Phase Optimisation” –

ACP3-GA-2013-605396

- **www.rbf4aero.eu**

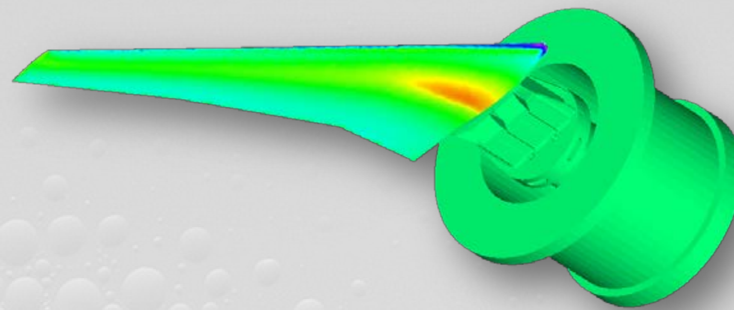


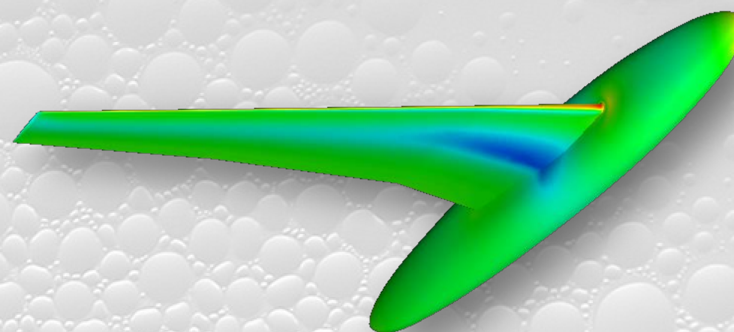
RBF4AERO

RIBES EU Project

- **R**adial basis functions at fluid **I**nterface **B**oundaries to **E**nvelope flow results for advanced **S**tructural analysis

JTI-CS-2013-GRA-01-052





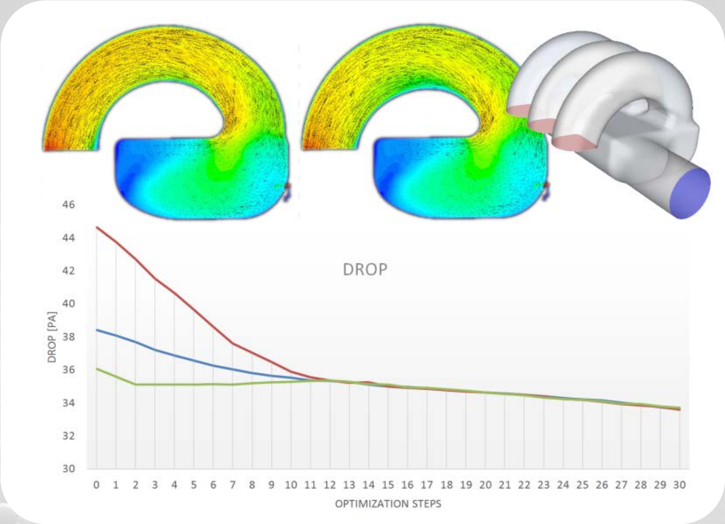
RIBES

CLEANSKY

Tor Vergata

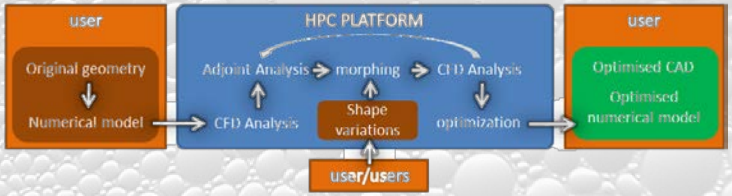
Fortissimo EU Project

- **F**actories **O**f the Future **R**esources, **T**echnology, **I**nfrastructure and **S**ervices for **SI**mulation and **MO**delling
- Approved experiment: "Virtual Automatic Rapid Prototyping Based on Fast Morphing on HPC Platforms"



FORTISSIMO

SuperComputing Applications and Innovation



RBF mesh morphing ACT extension for ANSYS Mechanical

Why mesh morphing?

- It allows to have parametric shape mesh that preserves the original topology. **Remeshing noise** is avoided.
- It allows to update the shape of a **validated FEM model** without rebuilding a new mesh.
- New shapes can be investigated even if the underlying **CAD geometry** is missing.
- The mesh can be updated to measured shapes (i.e. accounting for **manufacturing tolerances**)
- It's usually faster than remeshing.

Why RBF morphing?

- RBF Morph is a best in class product crafted to deal with challenging CFD application (**huge meshes**)
- 7 years of experience on industrial applications of Radial Basis Functions (RBF)
- RBF are **recognized** as one of the best mesh morphing tool available in the industrial and scientific community
- A new vision (we have started the new project from scratch) to put in the hands of **ANSYS Mechanical** Users the fastest and easiest mesh morphing tool
- Satisfy the needs of **many users** asking for such a kind of technology available in ANSYS Mechanical

ACT module specs

- Fully **embedded** in ANSYS Mechanical with same “look & feel”
- Integration in the tree and founded on the working principles of **ANSYS Workbench**
- Based on the ACT (Application Customization Toolkit) **extension** concept
- Geometrical and mesh scoping to set-up the mesh morphing problem
- Parametric (coming soon! In ANSYS 16 ACT modules parameters will be exposed natively)
- RBF **fast solver** (including parallel and GPU support)

ACT module specs

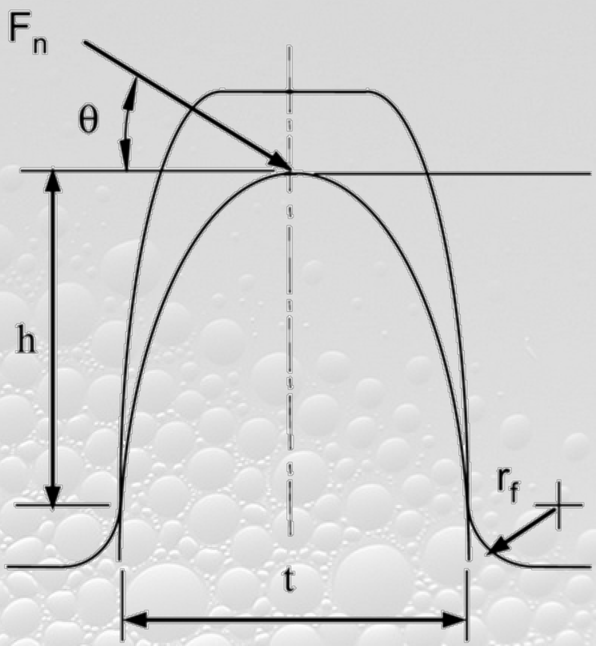
- Easy to use, flexible and **expressive**.
- Powered by multi-step RBF technology (which effectiveness has been extensively proven in RBF Morph)
- RBF **fitting and mesh morphing** happen as a unique **HPC process** at each shape update. This allows the maximum flexibility with respect to parameterization
- RBF component set-up data stored and persistent with the ANSYS Mechanical project.
- Advanced **interaction with DM** to enable CAD resynchronization after morphing (coming soon)

Current prototype

- **Hierarchical** multi-step RBF approach
- Each morphing **target** can be controlled using the superposition of a constant translation (other modifiers will be introduced) and an RBF field generated by its **sources** (if any)
- **Source points** are extracted using the motion of all the **children**
- If the child is a leaf its movement is known otherwise **it becomes a target** and has to be solved descending the tree
- Sounds complicated? Let’s explain it with an example!

Cube example

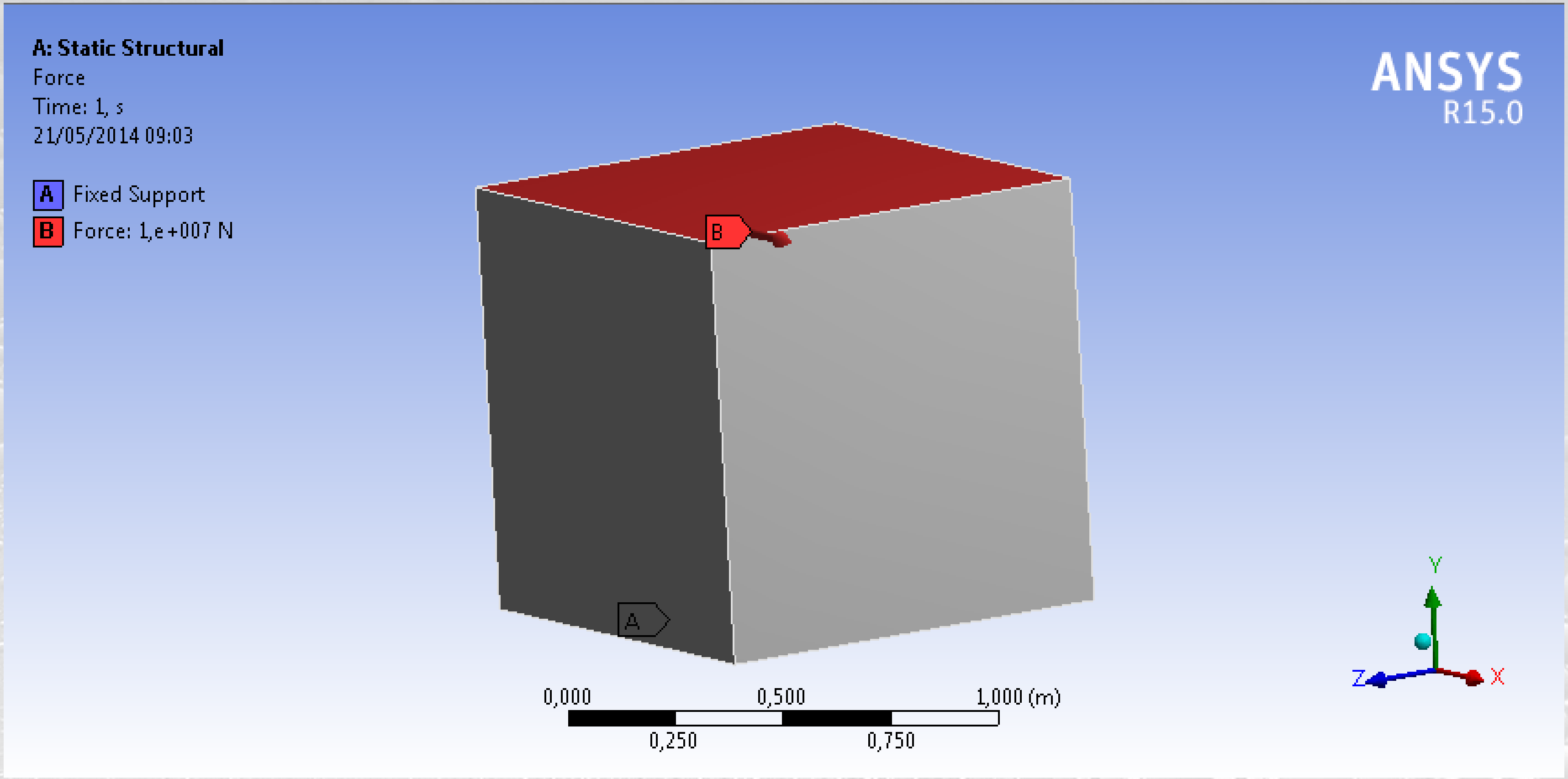
- A simple **cube** is loaded on the top and clamped to the bottom
- **Structural mechanics** tell us that this structure can be optimized adopting a tapered profile
- A parabola is obtained if we look for constant **bending stress** beam
- The theory is well known in gear design as the **Lewis formula** used for the stress assessment of a teeth



(b)

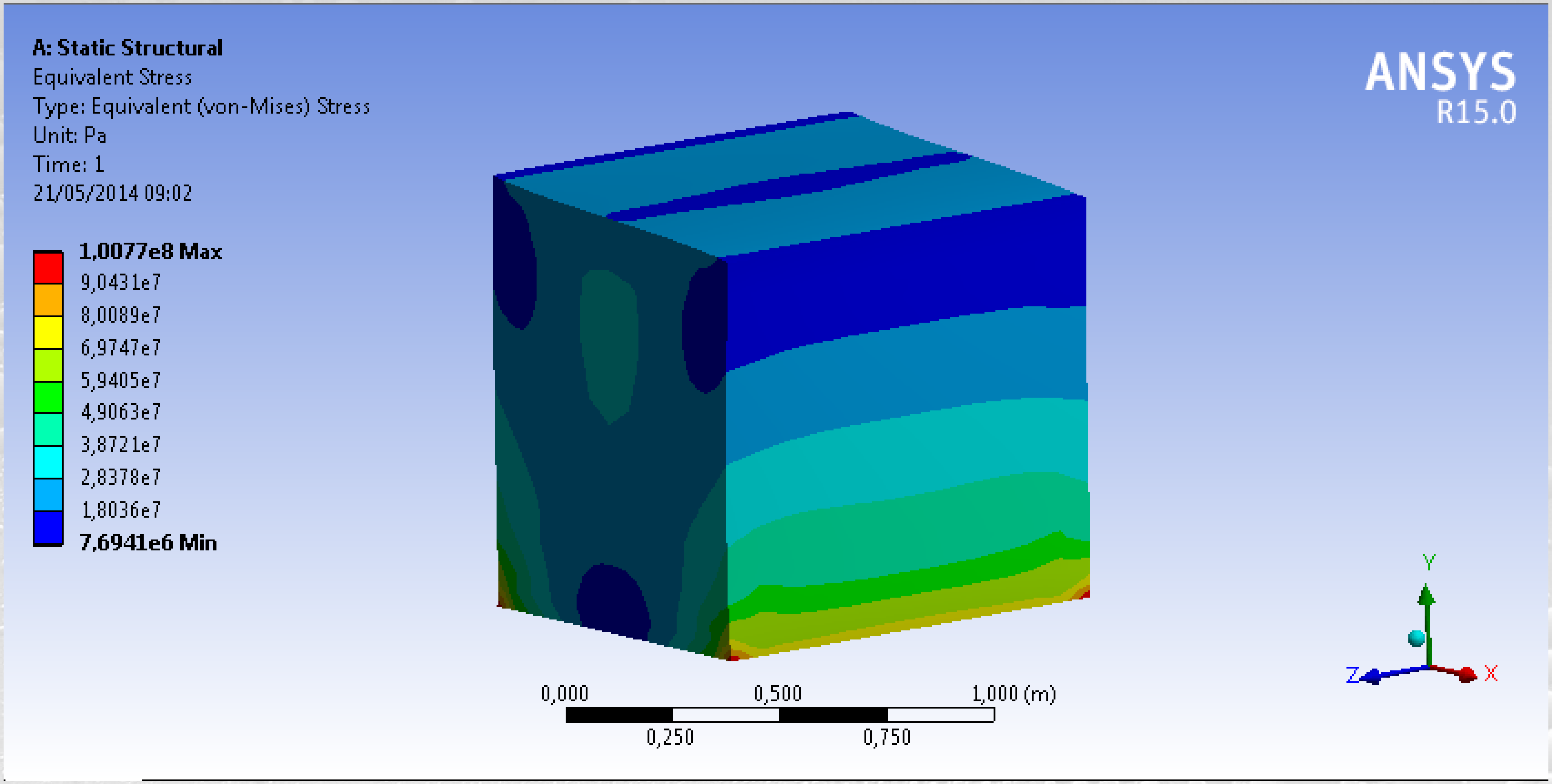
Cube example

- Boundary conditions



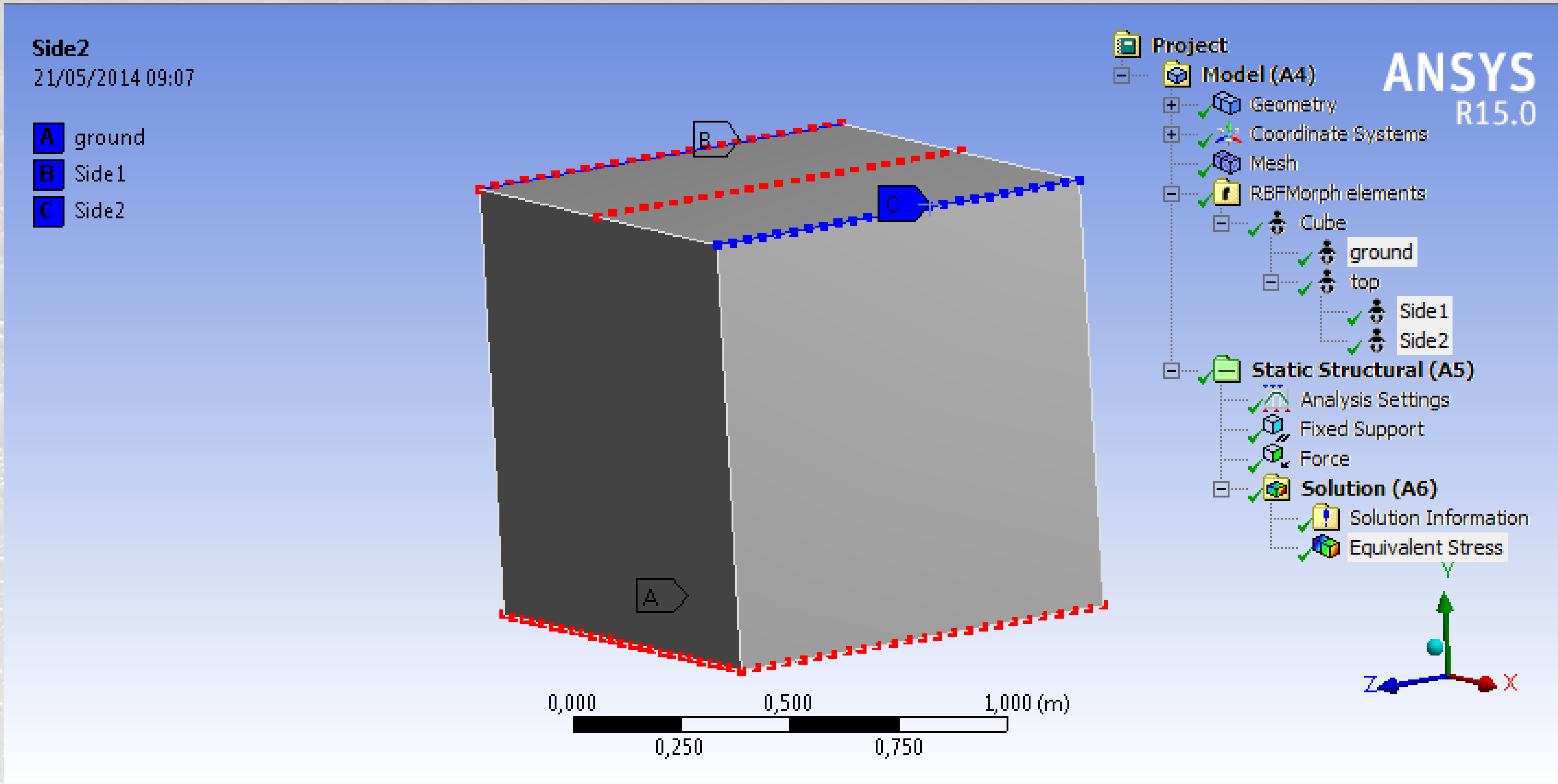
Cube example

- Baseline solution



Cube example

- First morphing set-up!

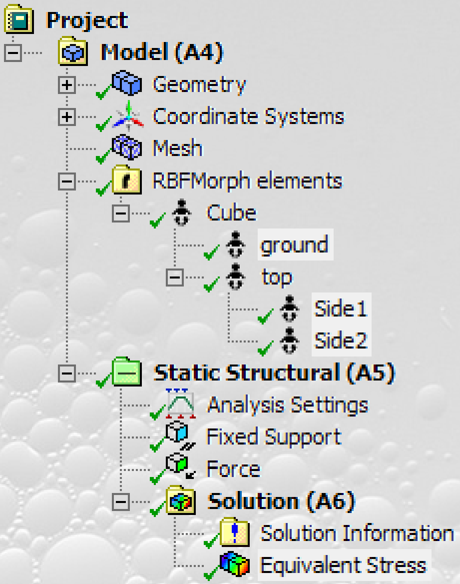


Cube example

- The first level set **Cube** (volume scoping) define the mesh to be morphed. Controlled by ground and top.

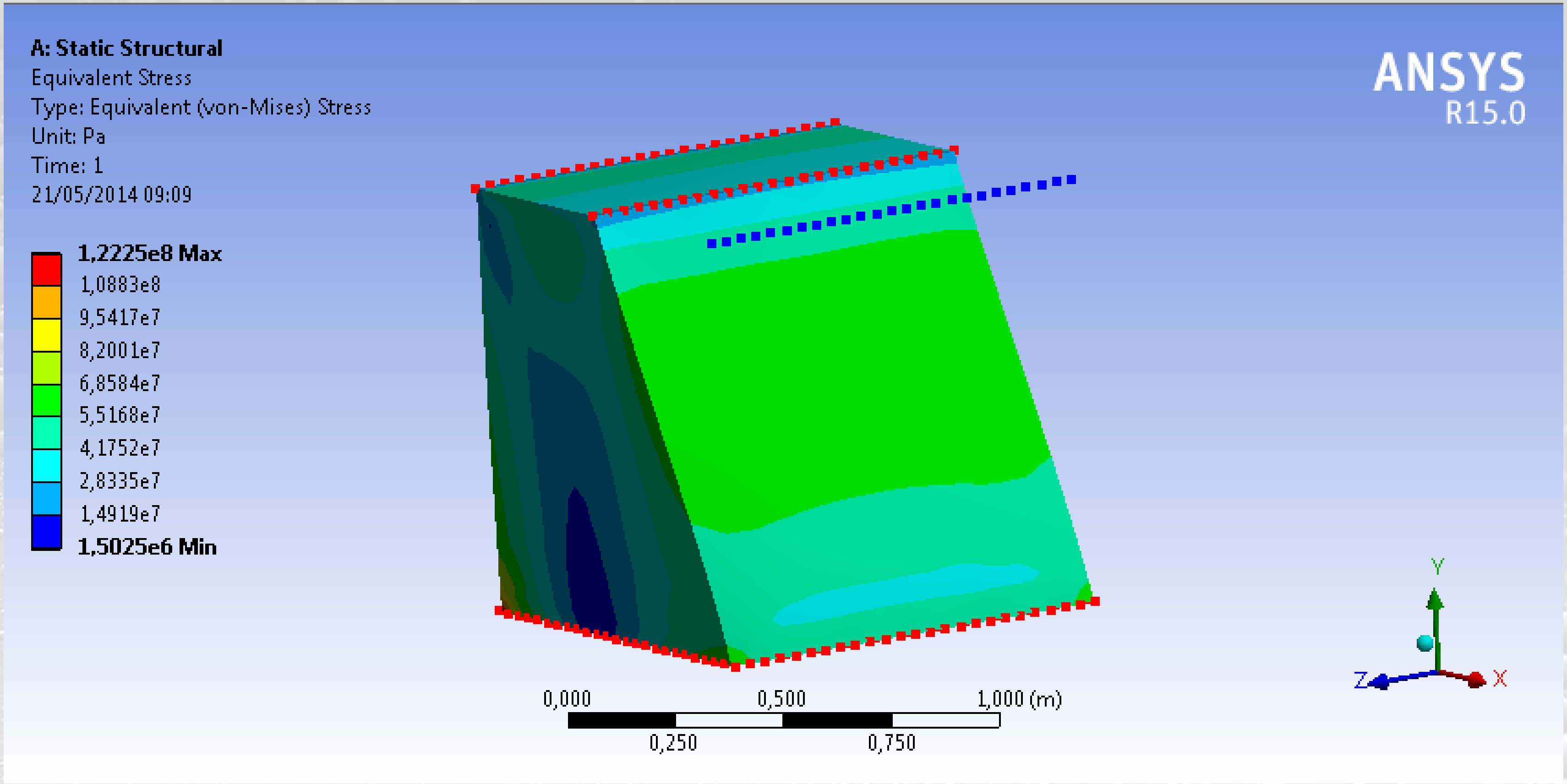
- At second level (surface scoping) we have two sets: **ground** (fixed and leaf of the tree) and **top** (controlled by Side1 and Side2).

- At third level (edge scoping) we have **Side1** (fixed) and **Side2** (moving in negative X direction).



Cube example

- Morphed solution #1

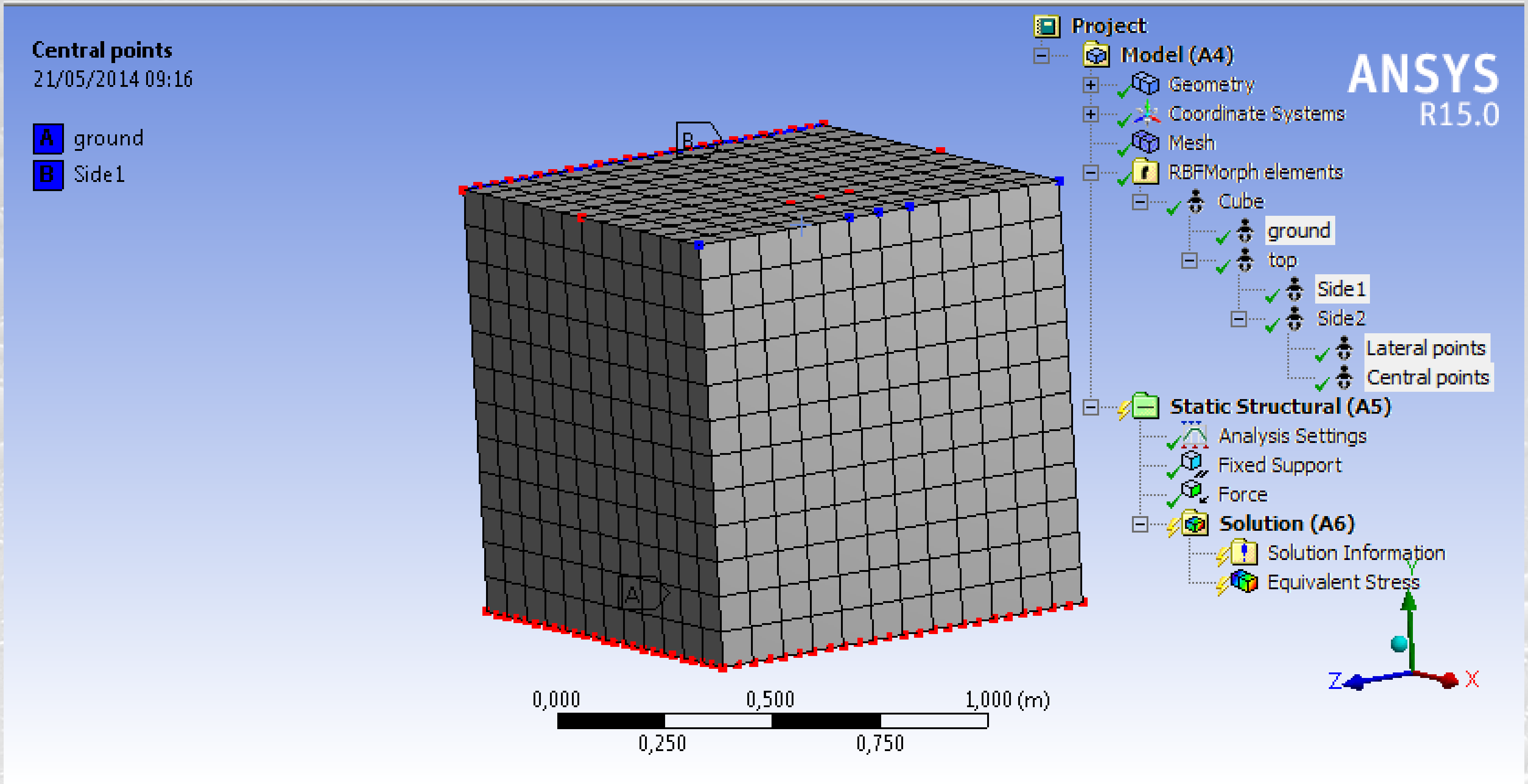


Cube example

(rbf-morph)™ Welcome to the World of Fast Morphing!

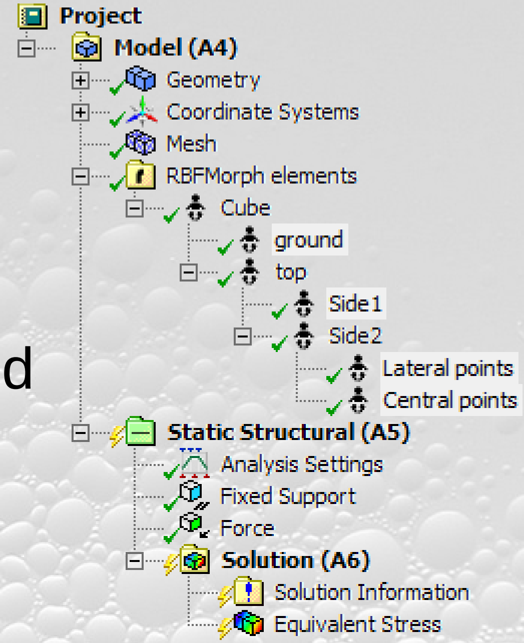
2014 Automotive Simulation World Congress

- Second morphing set-up!



Cube example

- The previous set-up has been refined and now we have a fourth level (scoping points and nodes) to control the shape of **Side2** that is controlled by Lateral Points and Central Points

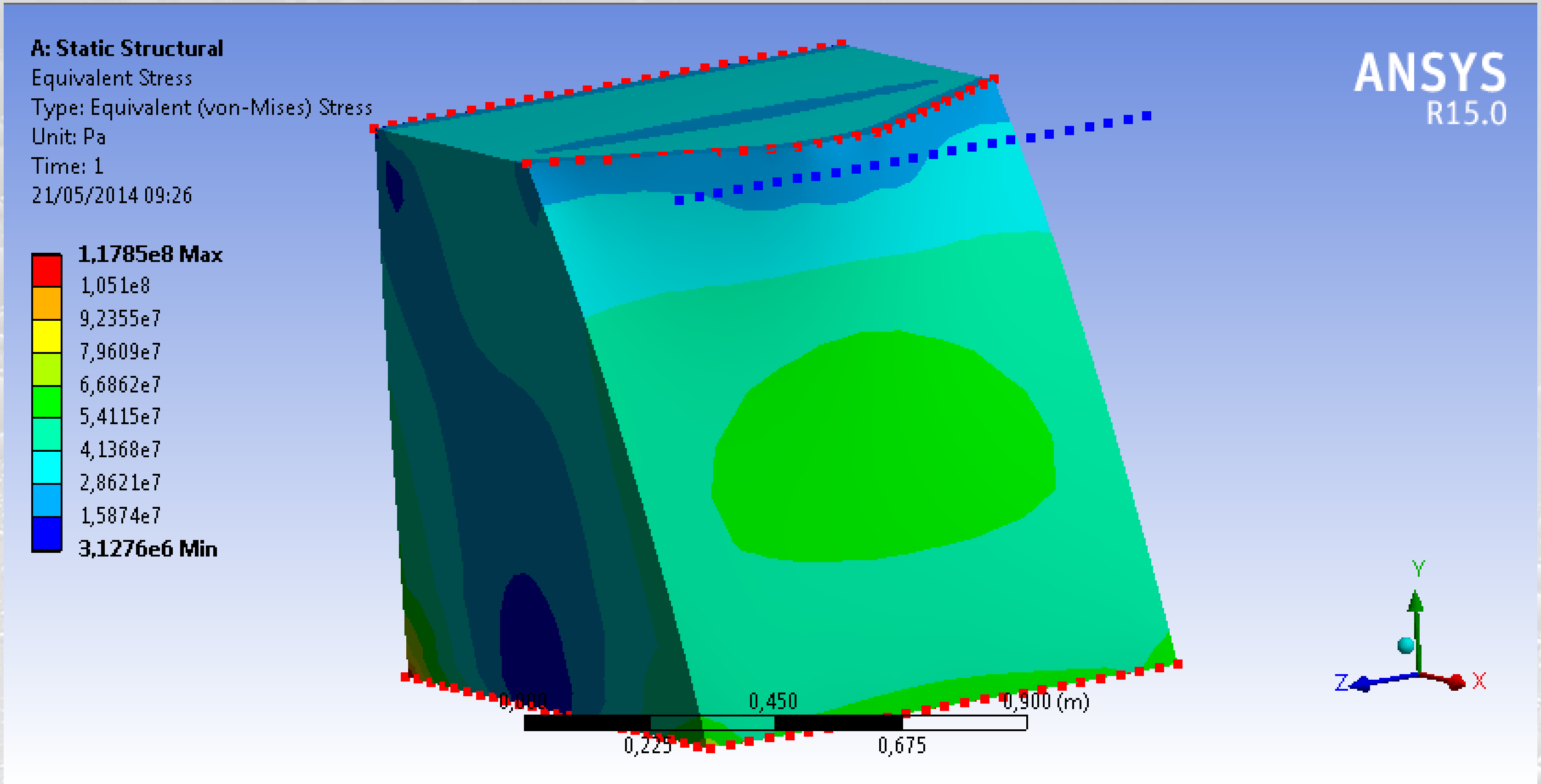


- Individual movements are imposed in the negative X direction to **Lateral Points** and **Central Points**

- At this level it would be good to control curvature changing the **order** of RBF function (coming soon!)

Cube example

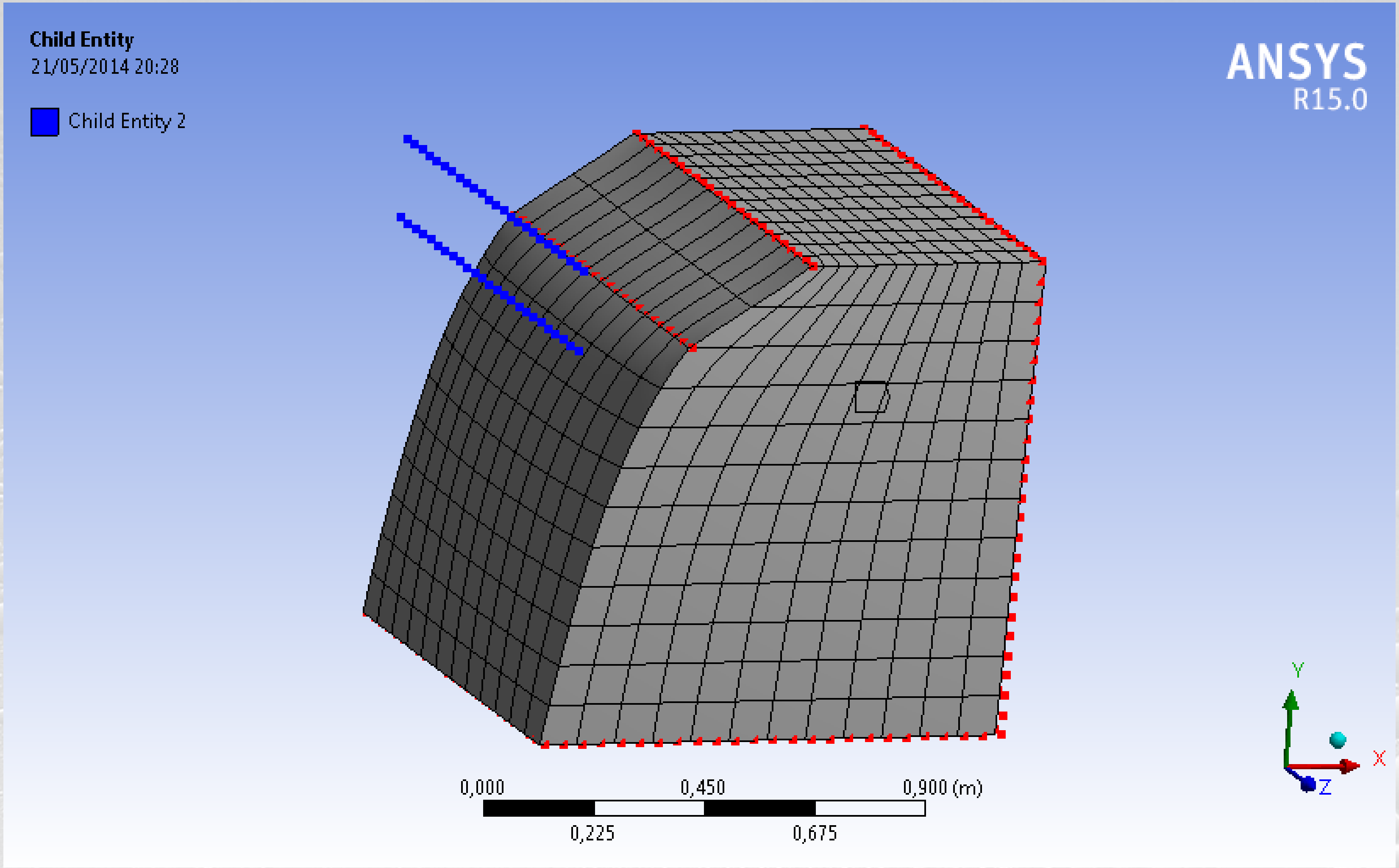
- Morphed solution #2



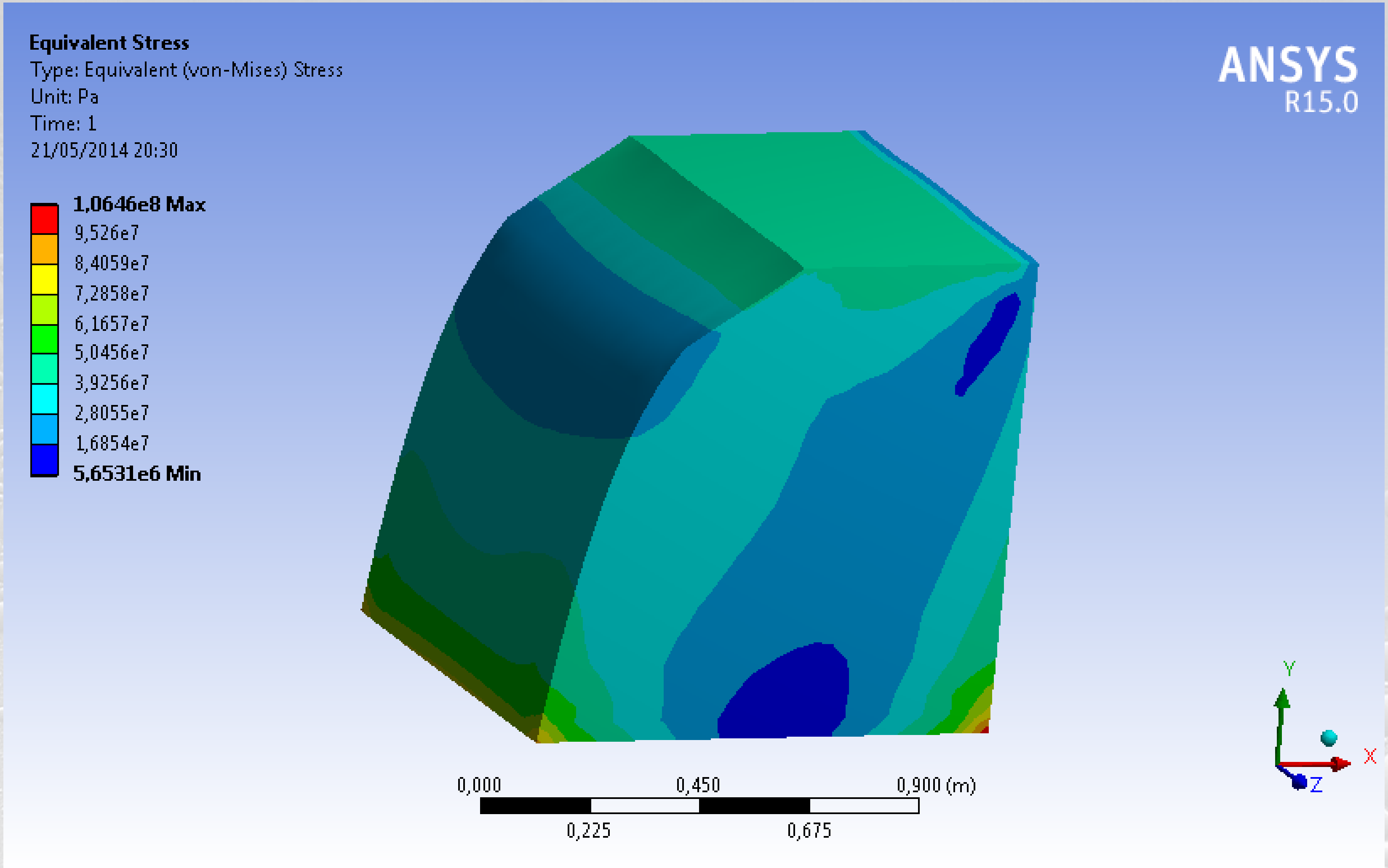
Cube example

- The set-up #1 and #2 are explained in detail.
- The set-up can be further enriched to fulfill the desired shape.
- Some example follows…

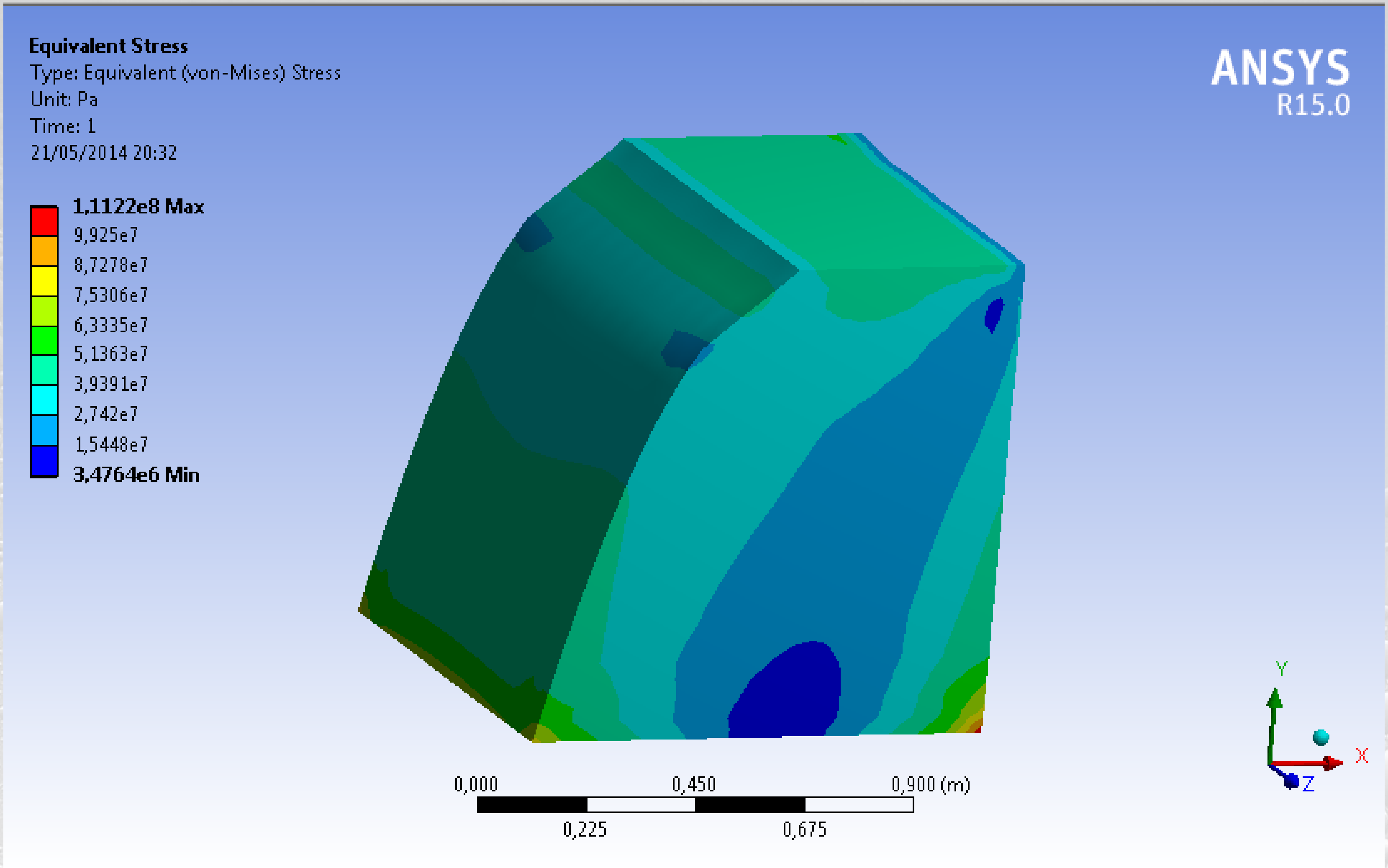
Cube example



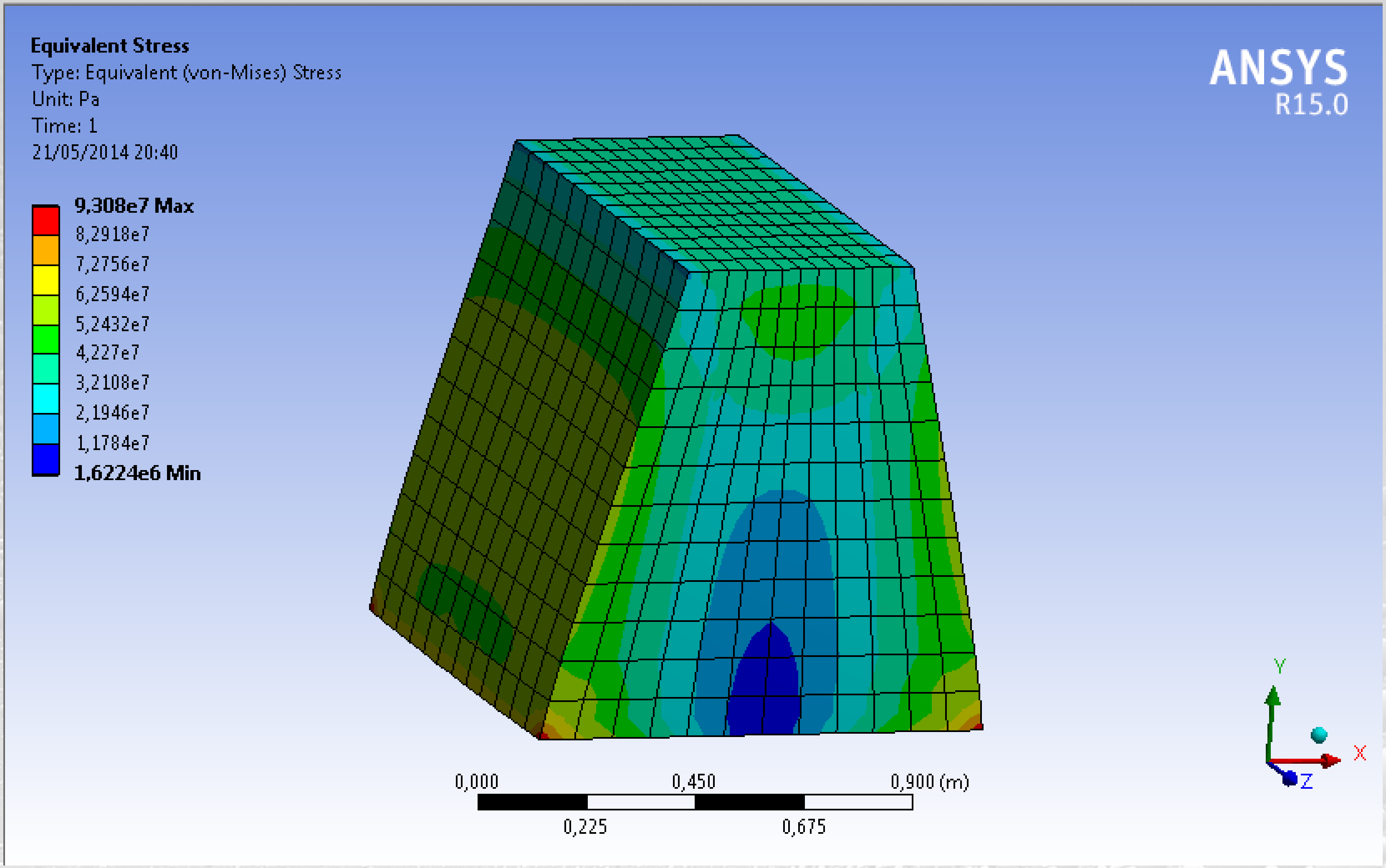
Cube example



Cube example

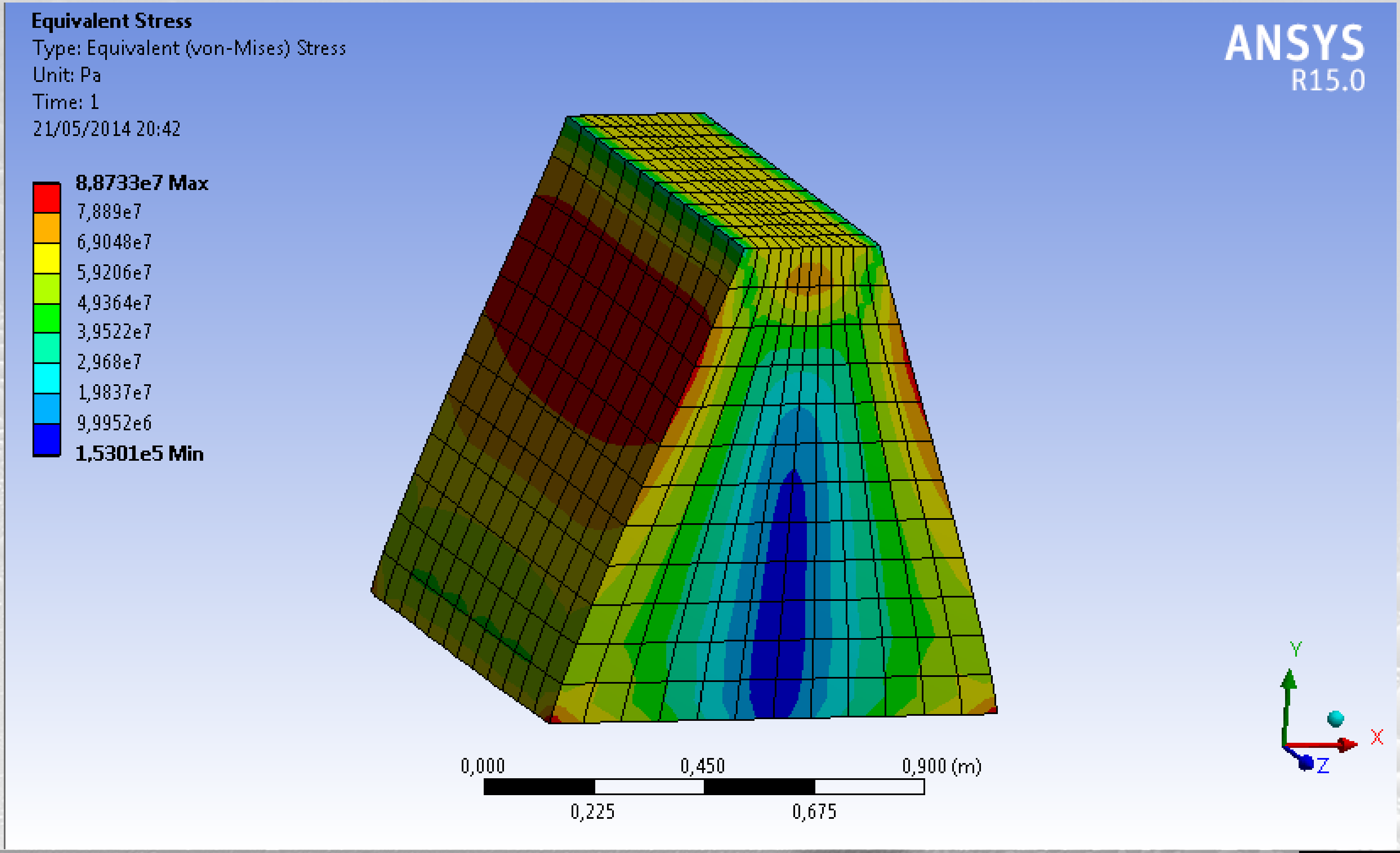


Cube example



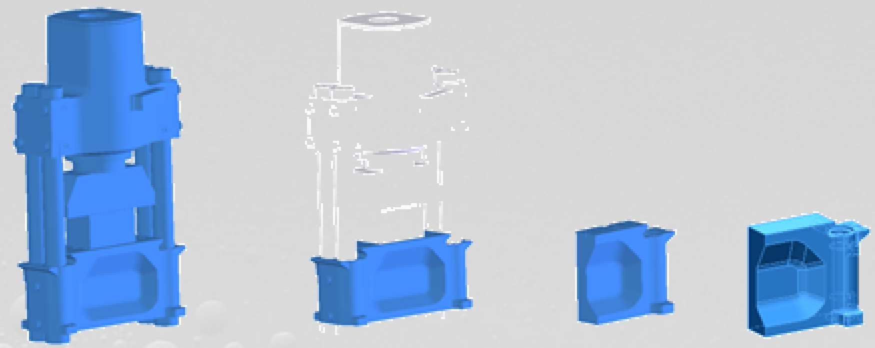
Cube example

- Mass reduction 36% Stress reduction 12%



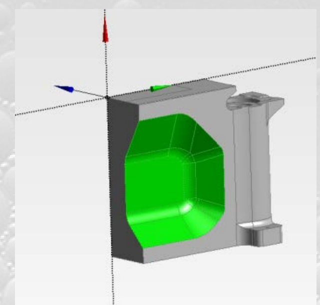
Press basement

SACMI



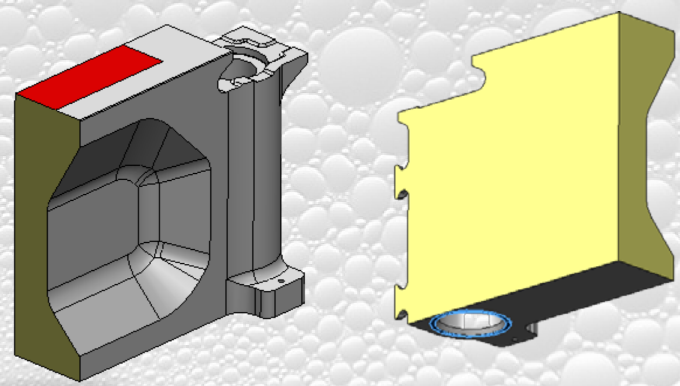
- This is a simple mesh morphing **feasibility study** for a geometry relevant for SACMI

- Part studied is a quarter of the basement of a press



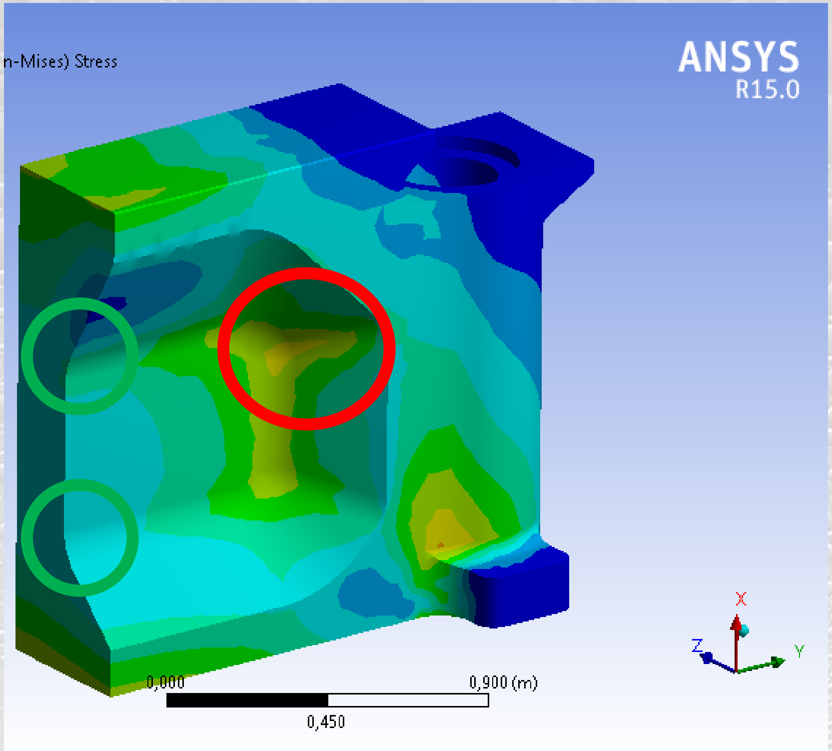
- Area to be optimized is the one highlighted in **green**

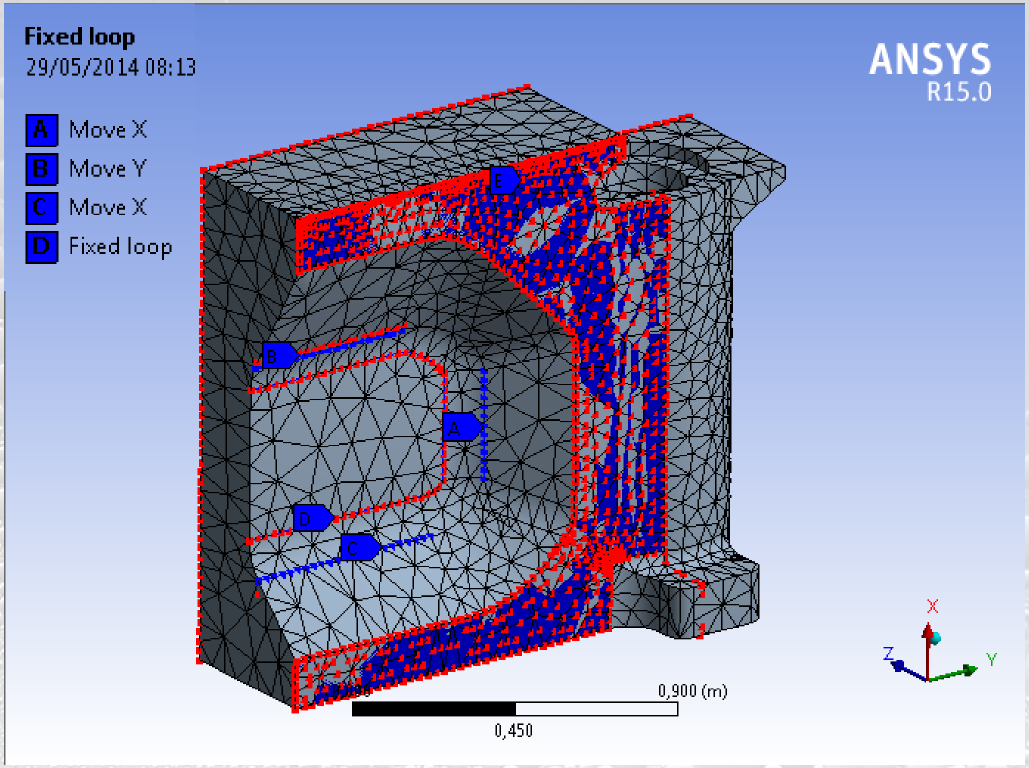
- **Simple boundary** conditions are used to stress the part (red fixed, yellow symmetry, blue loaded)



Press basement

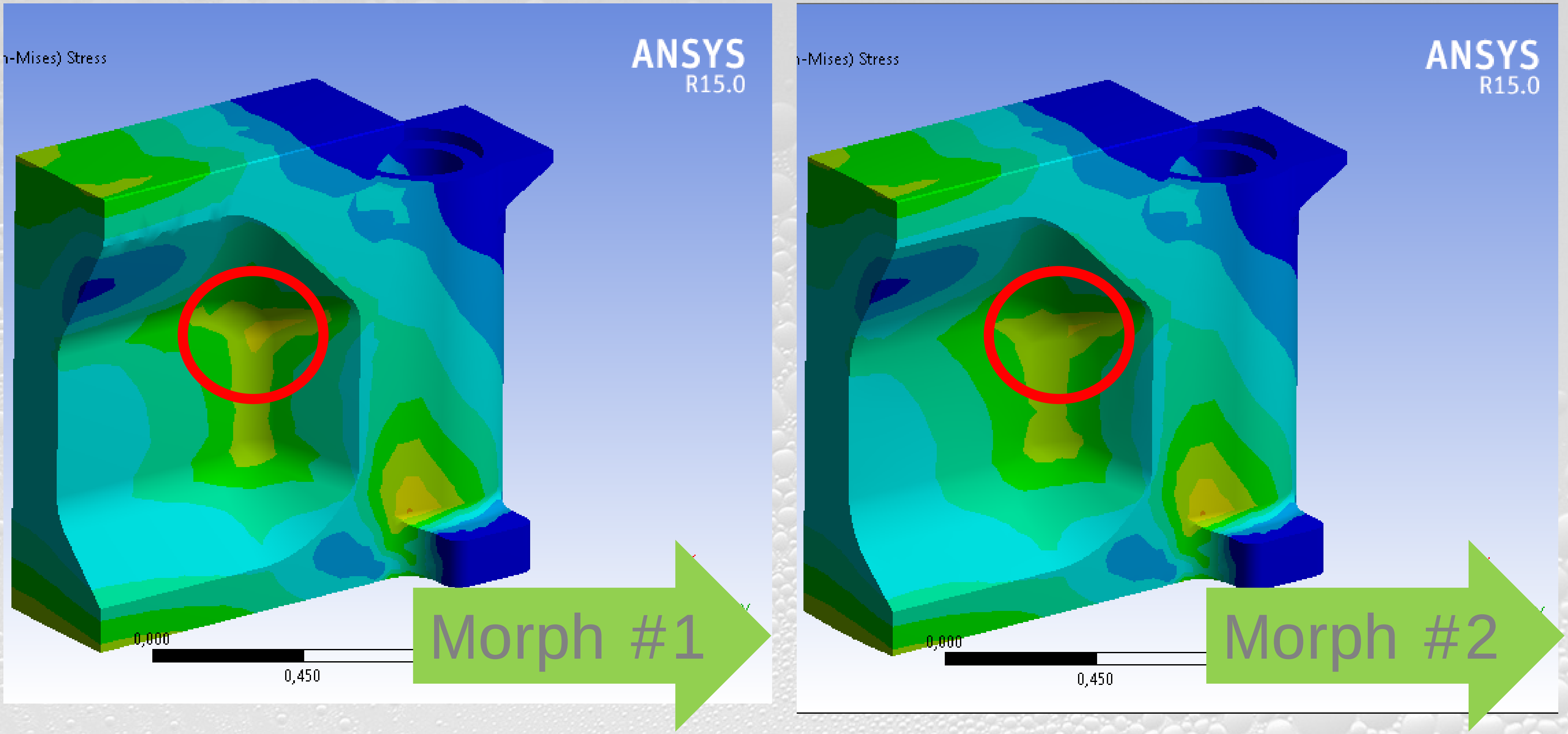
- Mesh morphing has been used to reduce the stress concentration acting on the shape of the fillet.





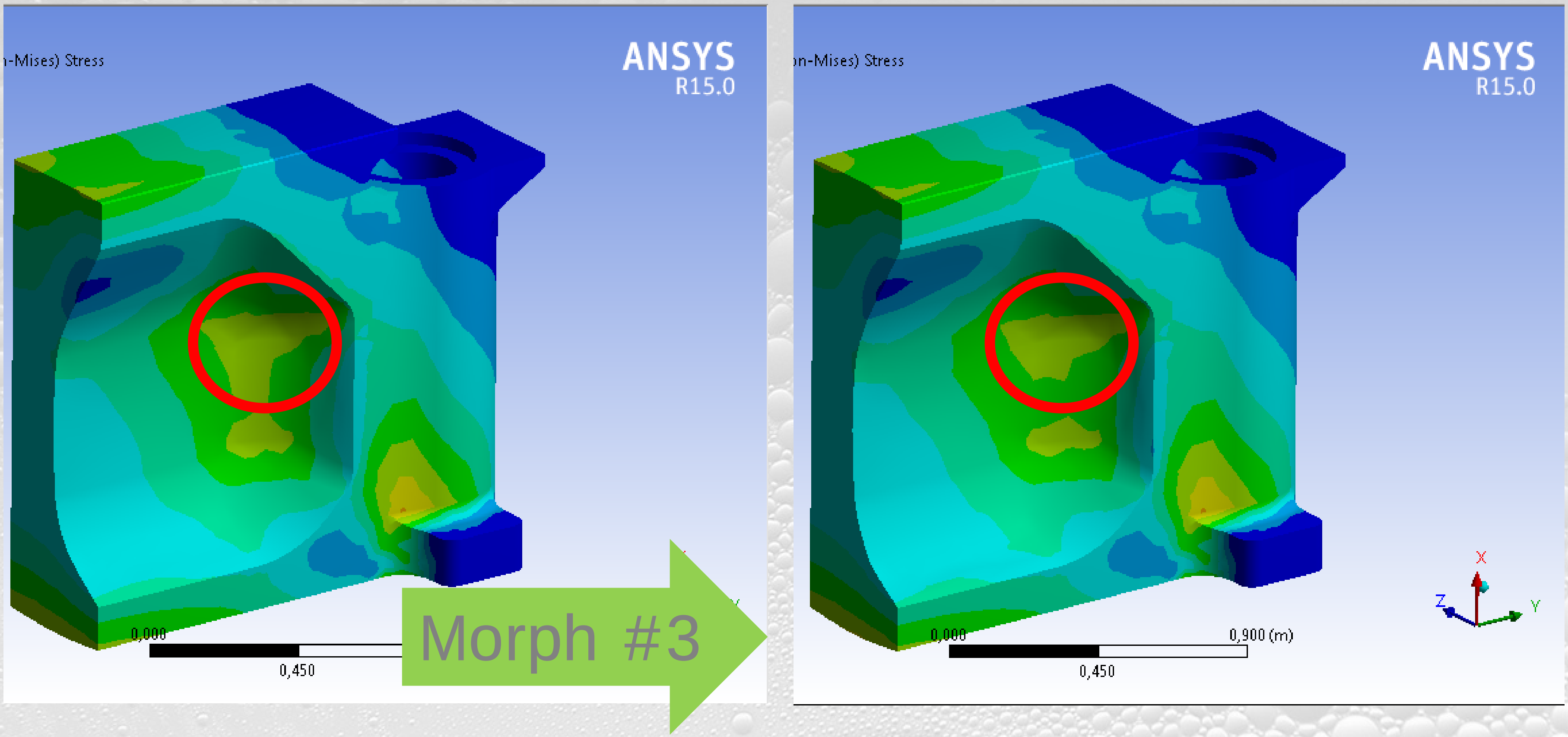
Press basement

- As the fillet is smoothed a stress redistribution is observed.



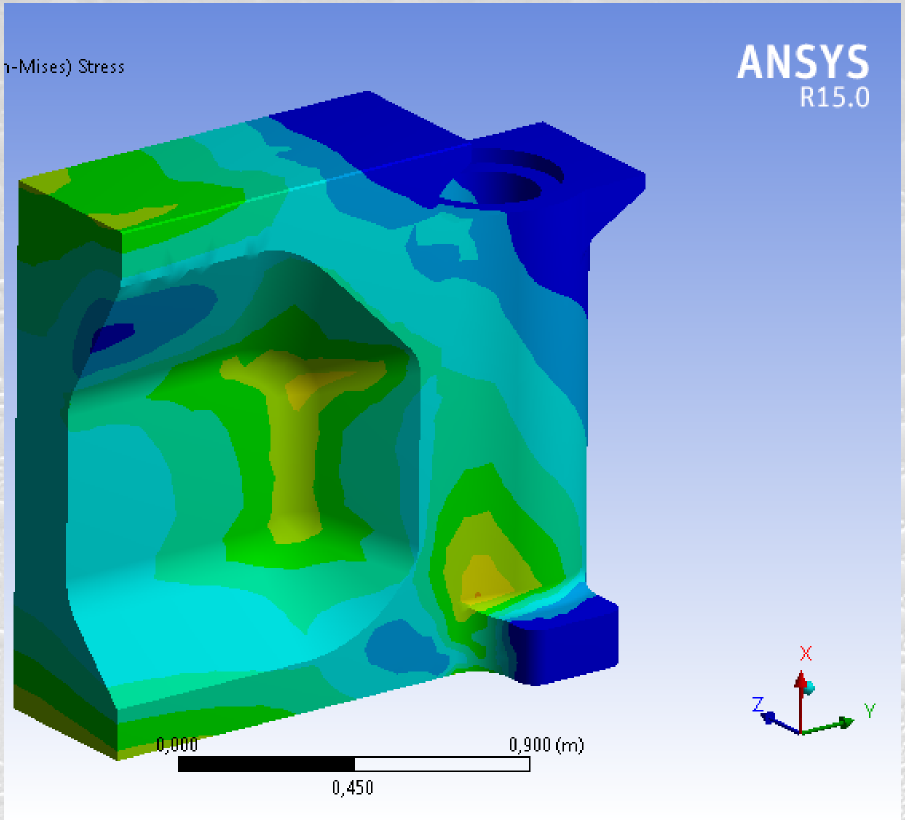
Press basement

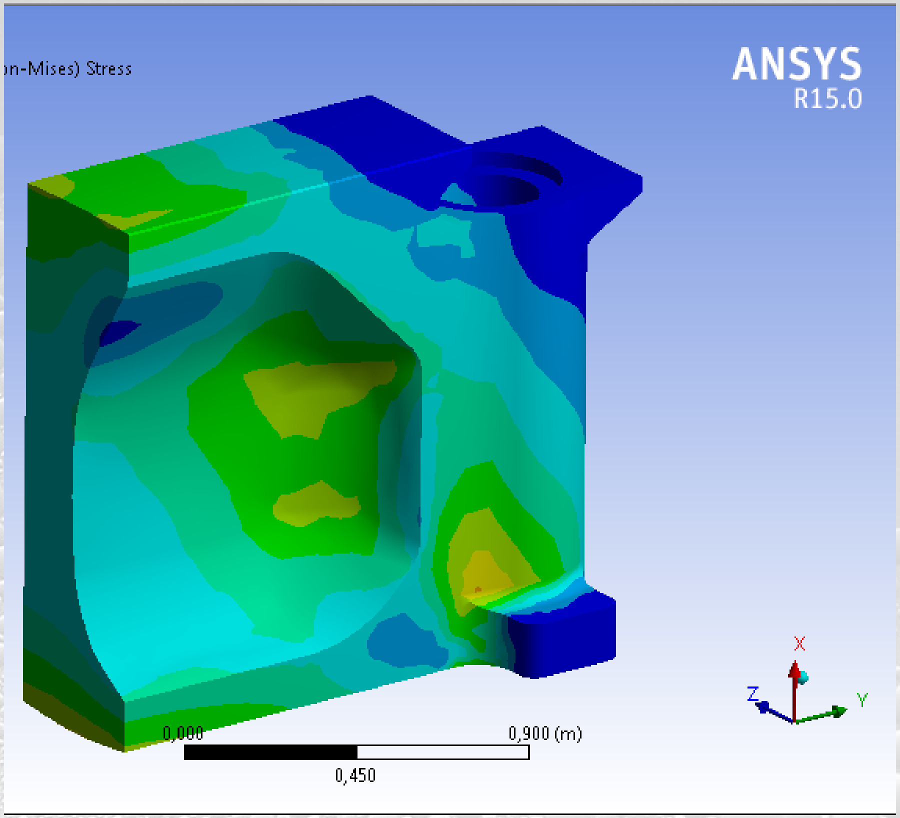
- Notice that high mesh deformation is properly accommodated thanks to RBF mesh morphing



Press basement

- Original vs. Optimised (13% reduction of stress peak)





Conclusions

- A novel mesh morphing tool has been implemented in **ANSYS Mechanical** using ACT extension technology
- **Radial Basis Functions** are used for multistep set-up
- The new software benefits of past experience on RBF Morph **ANSYS Fluent** add-on (mainly CFD)
- Nevertheless we have restarted all the developments **from scratch** i.e. reusing **knowledge** and **ideas** (no cross compatibility between tools)
- Basic capability of the first software prototype are demonstrated on a simple FEM mesh and on an **industrial FEM model**
- **How can we do better? Please do not hesitate to tell us your needs!**

ご清聴ありがとうございました!

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